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ECONOMIC EVALUATION AND SELECTION OF FARM MACHINERY

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ABSTRACT

This research is mainly conducted to study the farm machinery economic evaluation and selection the optimum tractor and implement sizes. The connection between draft and fuel consumption relative to the operation cost and machine selections is identified as a present idea to evaluate the tractor-plough operation. Therefore, the objective of this research is to use the economical method to select the tractor and plough for the tillage operation depending on the tractor-plough properties. For this reason the tractor tire specifications and the chisel plough properties are used by the visual basic program to calculate the fuel cost/fed at different tractor power, forward speed and plough width. The results showed that the suitable tractor can be used to tillage operation of 47.81 kW for all plough width and at different forward speed.

INTRODUCTION

The main factors for wrong and unsuitable choose of tractors and farm machinery are the shortage in basic information about it and the agricultural farms. The key of the basic information are depending on the requirements of power per feddan, machine size and finally the machinery costs. Machinery costs include costs of ownership and operation which equals to total machine costs. Ownership, operating, and total machine costs can be calculated on an annual, hourly, or per unit area basis. **Burton (2005)** indicated that ownership costs per unit area vary inversely with the amount of annual use of a machine. Therefore, a certain minimum amount of work must be available to justify purchase of a machine and, the more work available. **Kepner, et al. (1982); Hunt (1983); Butter and Johnnix (1983); Srivastava et al. (1995) and William (2005)** reported that, annual costs of operating a machine can be divided into two categories, fixed costs and variable costs.

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Fixed costs are independent on machinery use and include the following items:- a- Depreciation; b- Taxes; d- Insurance; e- Interest and shelter. Variable costs are those varying in proportion to the amount of machine use. It is including the following items: a- Repair and maintenance; b- Fuel and lubricant; c- Labor cost.

Al- Suhaibani (1989) indicated that the main variables affecting the variable cost is the fuel consumption during certain operation. He obtained data on costs of using farm machinery for wheat production on 41 farms in the mid region of Saudi. He analyzed data for individual operations as well as the total for each farm. The average total cost was 115.3 SR/ha (82.4 LE/fed) and the cost of ownership and operating cost (excluding timeliness) was 104.7 SR/ha. Fixed costs comprised 68.1 % of the total costs and variable costs, 31.9 %. The repair and maintenance cost share was 19.6 % while the fuel and oil cost share was less 3 % due to the government subsidy. While, **William (2005)** mentioned that fuel cost is calculated by multiplying the fuel consumption by the price of fuel. With fuel consumption assumed to be 0.044 gallons of diesel fuel per PTO horsepower-hour on average for each implement type. Fuel consumption per acre is averaged across sizes within a given implement type. The price of farm machinery diesel fuel is projected at $2.20 per gallon. All power unit, tractors, combine, truck, etc., use diesel fuel. Draft is an important parameter for evaluating implement performance and determining the required power consequentially calculate the required fuel consumption. **Gee-Clough et al. (1978)** modeled the tractor-plough performance using empirical relationships based on experimental data obtained from 14 different fields with sandy clay loam, clay loam, and sandy loam soils. Draft per unit width or cross-sectional area of the tilled zone is a function of soil type and the operating speed at which the implement is pulled **(Harrigan and Rotz, 1994).** The draft values for the moldboard plough, chisel plough, sub-soiler and standard chisel were all found to depend primarily on operating depth and the effect of speeds below 7.2 km/h was found to be small when compared with the depth effect **(Glancey et al., 1996)**.

The connection between draft and fuel consumption relative to the operation cost and machine selections was identified as a present idea to evaluate the tractor-plough operation. Therefore, the objective of this research is to use the economical method to select the tractor and plough for the tillage operation depending on the tractor-chisel properties.

THEORETICAL BASES

This research studies the cost operation and selects the suitable machine size as indication of the fuel consumption for the tillage operation. The theoretical attempts were carried out to determine the fuel consumption as function of wheels tractor specification. From the field survey, it was found that there were more than 20 famous tractors are used in Egyptian fields. The larger part of tractors power is ranging from 60 to 75 hp (Category 3). Table (1) shows the common tractor wheels specifications as the average of 20 foundations.

One of the most tractor wheel specification parameters is the gross traction ratio for wheel (C_{gi}). It's function for each of static loaded radius of wheel (r_{li}), bias-ply tiers constants, wheel slip (S) and wheel numeric (B_{ni}). While, the last parameter depending on section width of tractor wheels (b_i), section height (h_i), outside diameter of wheel (d_i) and the deflection of tire due to vertical loading (δ_i).

Table (1): The common tractor wheels specifications.

Items	Front	Rear
Dynamic vertical load on wheel (R_i), (kN)	14.66	18.72
Effective cone index for wheel (CI_i), (N/mm^2)	1.5	
Section width of wheel (b_i), (mm)	152.399	528.574
Nominal rim diameter for the wheel (d_{nri}), (in)	16	42
Nominal section width (b_{ni}), (in)	9.5	14.9
Motion resistance force on wheel (R_{mi}), (kN)	0.45	0.55
Actual travel speed of vehicle (V_a), (m/s)	0.79– 1.805	
Engine speed (n_e), (rev/min)	2000	
Power train speed ratio for wheel (N_{pti}), (rev/min)	0.72	1.44
Traction force on wheel (R_{ti}), (kN)	8.90	16.5
rotational speed of wheel (W_i), (rad/s)	40	16

The following equations **(Srivastava et al., 1995)** can be used to determine the gross traction ration for wheel (C_{gi}) which,

$$\frac{T_i}{r_{li} \cdot R_i} = C_{gi} = 0.88(1-e^{-0.1Bni})(1-e^{-K_1 S}) + K_2 \qquad \text{……….(1)}$$

Where:

i = (f) for a front wheel or (r) for a rear wheel

T_i = Traction–limited torque on wheel (i), N.m

K_1 = constant = 7.5 for bias-ply tiers or (8.5 to 10.5) for radial

K_2 = constant =0.04 for bias-ply tiers or (0.03 to 0.035) for radial tires

To solve the above equation, it must be determine the wheel numeric which may be calculated from the following equation:

$$B_{ni} = \frac{CI_i b_i d_i}{1000 R_i} \times \frac{1 + 5 \delta_i / h_i}{1 + 3 / r_A} \qquad \text{…….(2)}$$

Where:

r_A = aspect ratio = section height / section width

The out side diameter and static loaded radius of wheel can be calculated from the following equations:

$$d_i = 25.4\left(\frac{d_{nri}}{2} . \ 2\, r_A \cdot b_{ni}\right) \qquad \text{……….(3)}$$

$$r_{li} = 25.4\left(\frac{d_{nri}}{2} . \ 0.81\, r_A \cdot b_{ni}\right) \qquad \text{………..(4)}$$

While, the deflection of tire due to vertical loading can be calculated from:

$$\delta_i = \frac{d_i}{2} - r_{li} \qquad \text{………..(5)}$$

r_{li} = static loaded radius of wheel (mm)

d_i = outside diameter of ith wheel (mm)

The section of wheel height can be found from the equation of

$$h_i = \frac{d_i - 25.4 d_{nri}}{2} \qquad \text{………..(6)}$$

Consequentially, the motion resistance force for wheel may be found as a function of motion resistance coefficient for wheel from the relation:

$$\frac{R_{mi}}{R_i} = \rho_i = K_2 + \frac{K_3}{B_{ni}} + 0.5 \times S \times B_{ni}^{-o.5} \qquad \text{………..(7)}$$

Where:

K_3 = constant = 0.1 for bias- ply tires or 0.9 for radial tires

ρ_i = motion resistance coefficient for (i) wheel

Consequentially, the net traction ratio essay found from the coefficient of wheel motion resistance as follows:-

$$C_{ni} = C_{gi} - \rho_i \qquad \text{………..(8)}$$

Where: C_{ni} = net traction ratio

The amount of wheel slippage can be found from the equation of

$$S = 1 - \frac{V_a}{V_{ti}} \qquad \text{………..(9)}$$

Where:

V_{ti} = theoretical travel speed of (i) wheel (m/s)

The theoretical travel speed can be calculated from the following equation;

$$\mathbf{v}_{ti} = \frac{\pi \mathbf{n}_e \mathbf{r}_{li}}{30000 \mathbf{N}_{pti}} \qquad \text{………..(10)}$$

Then the tractive performance can be found as;

$$\mathbf{F}_{hx} = \mathbf{c}_{nr} \cdot \mathbf{R}_r + \mathbf{c}_{nf} \cdot \mathbf{R}_f \qquad \text{………..(12)}$$

Where:

R_r = combine dynamic load on all wheels on the rear axle

R_f = combined load on all front wheel

F_{hx} = tractive performance of an entire vehicle

Then, the total power (P_{db}-drawbar power in kW) can be calculated from:-

$$\mathbf{p}_{db} = \mathbf{v}_a \cdot \mathbf{F}_{hx} \qquad \text{………..(13)}$$

The approximated draft for chisel plough may be predicted from the following equation,

$$\text{Draft} = A \times S_{sr} \qquad (14)$$

Where:

A = ploughed cross sectional area

$\mathbf{S_{sr}}$ = the soil specific resistance

But, the soil specific resistance is the resistance per unit area. it is naturally varies with the texture, quality and condition of the soil, shape and operating speed of the ploughs. The soil specific resistance for clay soil is 0.968 kN\m^2.

The ploughed cross sectional area for any chisel plough may be predicted according to figure (1) and Equation (15).

$$A = (n-1)\left(2d - \frac{S_b - t}{2}\right)\left(\frac{S_b - t}{2}\right) + (n \times t \times d) + d^2 \qquad \text{..........(15)}$$

Where:

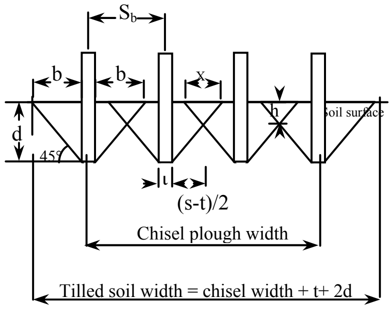
A : predicted ploughing soil cross sectional area, cm^2.

n : number of chisel plough tines.

S_b : space between each two adjacent tines, cm.

t : tine width, cm.

d: adjustable ploughing depth, cm.



N.t.

b: will be equal d.

S_b: Space between each two adjacent tines.

x: Overlap tilled soil.

Figure (1): The actual width of chisel plough with overlap tilled soil.

If knowing the predicated draft, then the fuel consumption easy to calculate acording to **ASAE (1998)** equations. Then economic equations may be utilized to select the optimum tractor and implement sizes.

MATERIALS AND METHODS

Estimated field capacity: To estimate the fuel cost it is necessary to determine the field capacity which can be calculated using the following equation:

$$C_a = \frac{W \times F \times Va}{4200} \quad \text{fed/h} \qquad \text{..........(16)}$$

Where:

w = Width of Implement (m)

F = Field Efficiency of Implement (%)

V_a = actual travel speed of vehicle (m/h)

Estimated fuel consumption: Predicting fuel consumption for a specific operation can be estimated by **ASAE (1998)** as following calculation:

$$Q_i = Q_s \cdot p_{db} \qquad \text{..........(17)}$$

Where:

Q_i = estimated fuel consumption for a particular operation L/h

Q_s = specific fuel consumption for the given Tractor L/kW.h

While, the specifisc fuel consumption (Q_s) may be calculated from the equation as follows:-

$$Q_s = 2.64\ x + 3.91 - 0.203\ (738\ x + 173)^{0.5} \qquad \text{........(18)}$$

Where; (x) is the ratio of equivalent PTO power required by an operation to that maximum available from the PTO, this ratio depending on draft and speed of implement.

Then the fuel cost can be calculated using the Srivastava, et al. (1995) equation as follows:

$$C_s = \frac{P_I \times Q_i}{C_a} \qquad \text{..........(19)}$$

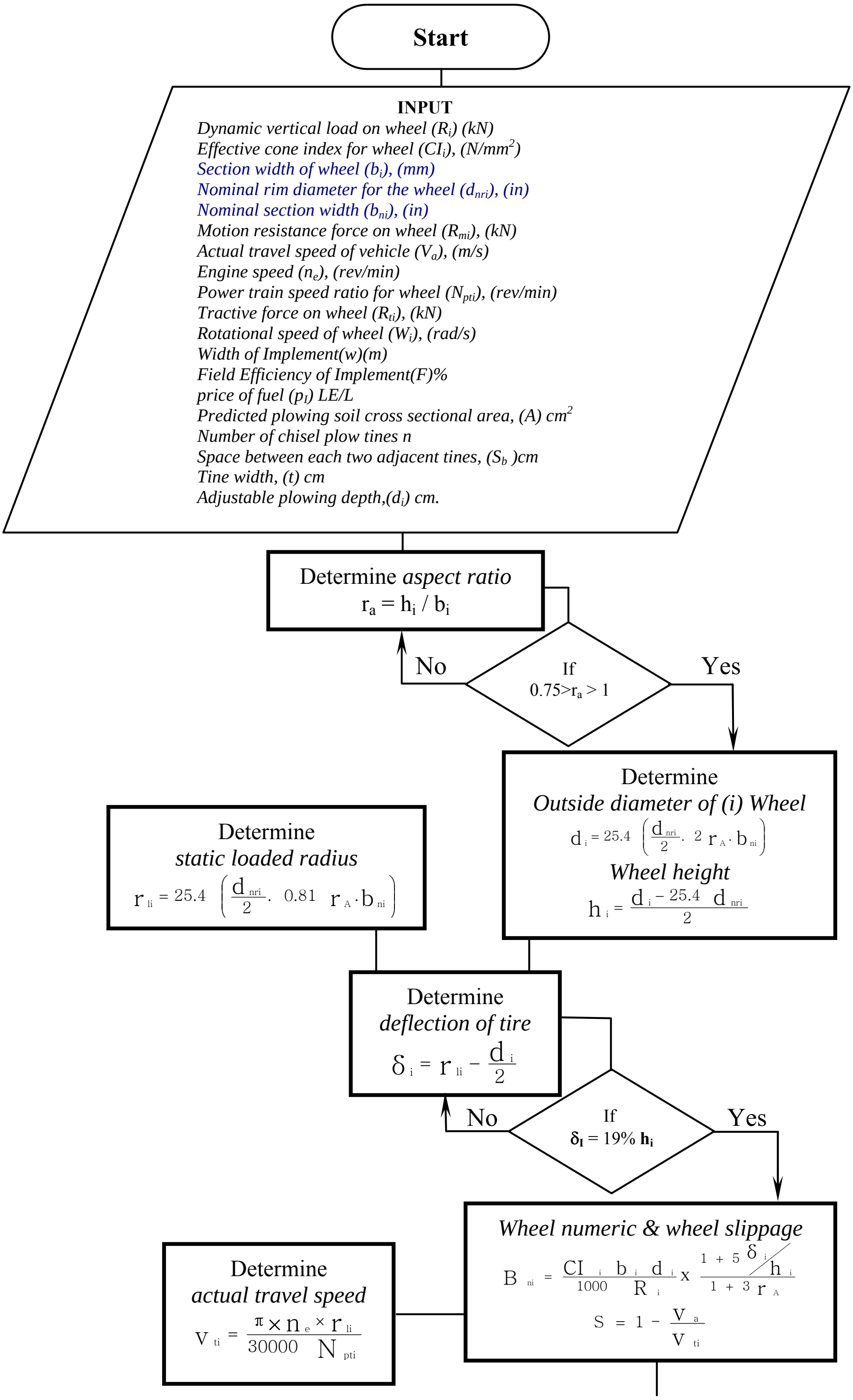
Where:

C_s = fuel costs per-feddan, LE/fed

p_I = price of fuel (oil) LE/L

C_a = effective field capacity during operation fed/h

The mathematical model: To determine the tractor fuel consumption during the tillage operation, same factor to account for the fuel consumption may be used of tractor tire specification. These factors for tractor power ranging from 44.13 to 55.16 kW and forward speeds from 0.97 to 1.81 m/s by using the chisel ploughs 3, 5 and 7 shares. The following mathematical model was built on Visual Basic program to predict the drawbar power and fuel cost at tillage operation. The flow chart of the proposed model was shown in figure (2). The input data for the mathematical model were represents with their units in figure (3).


Start
INPUT
Dynamic vertical load on wheel (R_i) (kN)
Effective cone index for wheel (CI_i), (N/mm^2)
Section width of wheel (b_i), (mm)
Nominal rim diameter for the wheel (d_{nri}), (in)
Nominal section width (b_{ni}), (in)
Motion resistance force on wheel (R_{mi}), (kN)
Actual travel speed of vehicle (V_a), (m/s)
Engine speed (n_e), (rev/min)
Power train speed ratio for wheel (N_{pti}), (rev/min)
Tractive force on wheel (R_{ti}), (kN)
Rotational speed of wheel (W_i), (rad/s)
Width of Implement(w)(m)
Field Efficiency of Implement(F)%
price of fuel (p_l) LE/L
Predicted plowing soil cross sectional area, (A) cm^2
Number of chisel plow tines n
Space between each two adjacent tines, (S_b)cm
Tine width, (t) cm
Adjustable plowing depth,(d_i) cm.
Determine aspect ratio
$r_a = h_i / b_i$
If
$0.75 > r_a > 1$
No
Yes
Determine
Outside diameter of (i) Wheel
$d_i = 25.4 \left(\frac{d_{nri}}{2} . \ 2 \ r_A \cdot b_{ni} \right)$
Wheel height
$h_i = \frac{d_i - 25.4 \ d_{nri}}{2}$
Determine
static loaded radius
$r_{li} = 25.4 \left(\frac{d_{nri}}{2} . \ 0.81 \ r_A \cdot b_{ni} \right)$
Determine
deflection of tire
$\delta_i = r_{li} - \frac{d_i}{2}$
If
$\delta_I = 19\% \ h_i$
No
Yes
Wheel numeric & wheel slippage
$B_{ni} = \frac{CI_i \ b_i \ d_i}{1000 \ R_i} \times \frac{1 + 5 \ \delta_i / h_i}{1 + 3 \ r_A}$
$S = 1 - \frac{V_a}{V_{ti}}$
Determine
actual travel speed
$V_{ti} = \frac{\pi \times n_e \times r_{li}}{30000 \ N_{pti}}$

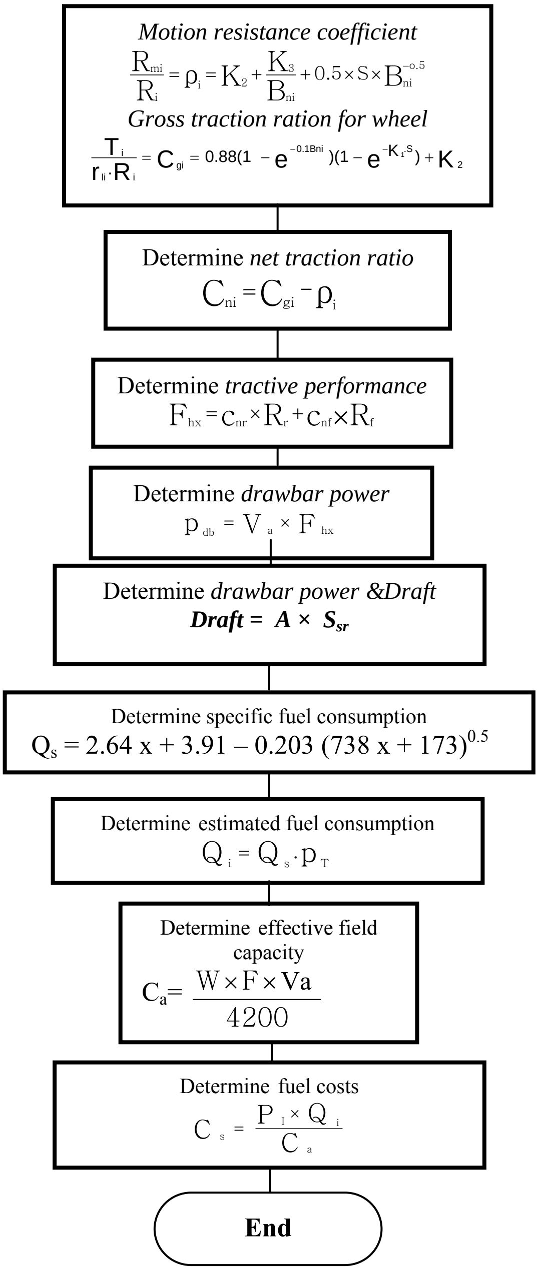


Figure (2): Flow chart of the proposed model for fuel cost.

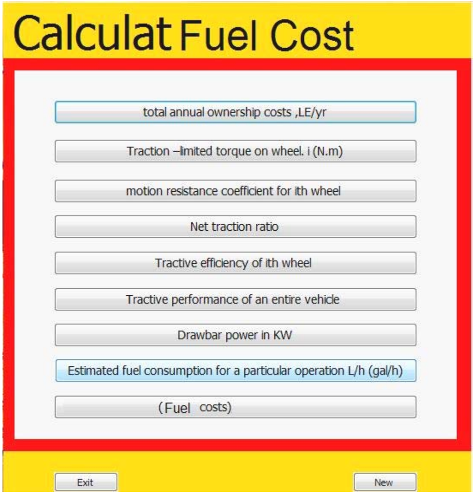


Figure (3): Input data and their measuring units for fuel cost at tillage operation as presented in Visual Basic program.

RESULTS AND DISCUSSION

1- The relationship between tractor wheel specifications and the slippage

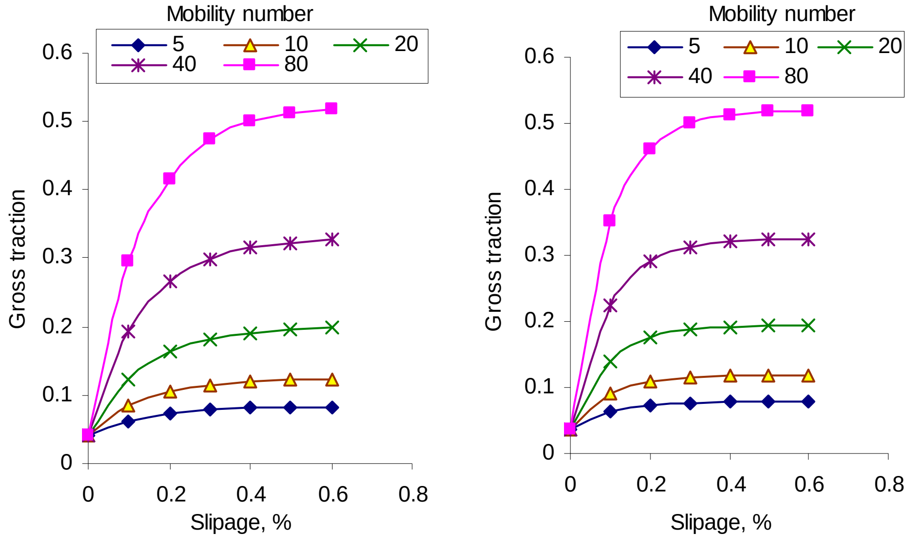
A- The gross traction ratio

The data for the relationship between tractor wheel specifications and the slippage are calculated from Eq. 1 to Eq. 12 using the visual basic program. Then the obtained data illustrate in figures 4 to 7.

Figure 4 clears that the relation between the gross traction (C_{gi}) via the slippage at different tractor mobility number (B_{ni}) for front and rear tractor wheels. At mobility number 5 and by increasing the slippage from 0 to 0.6 % the gross traction increases from 0.035 to 0.246 and from 0.040 to 0.250 for front and rear wheel respectively %. Generally, by increasing the slip phenomena the values of gross traction directly increases. But the increases rates are very immense at increase the wheel slippage from zero to 0.25. Increasing the slippage percentage of tractor wheels from 0.3 to 0.6 the change of rate of gross traction are very closes.

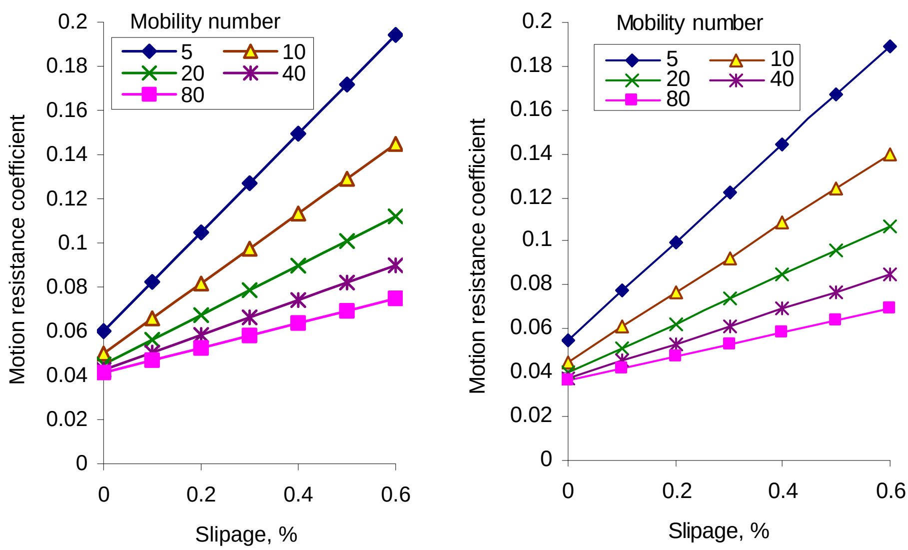
B- The motion resistance coefficient

Figure 5 illustrates the relationship between the motion resistance coefficients (ρ_i) and the tractor wheels slip at different tractor mobility number for front and rear wheel. The figure clears that at the slippage increase from 0.0 to 0.6% the motion resistance coefficient increased from 0.043 to 0.118 and from 0.048 to 0.123 respectively at front and rear wheel. Moreover, the relation between the increase of mobility number from 5 to 80 the motion resistance coefficient decrease from 0.122 to 0.053 and 0.127 to 0.058 respectively at front and rear wheel.



Front wheel **Rear wheel**

Figure 4: The relation between the gross traction via the slippage.

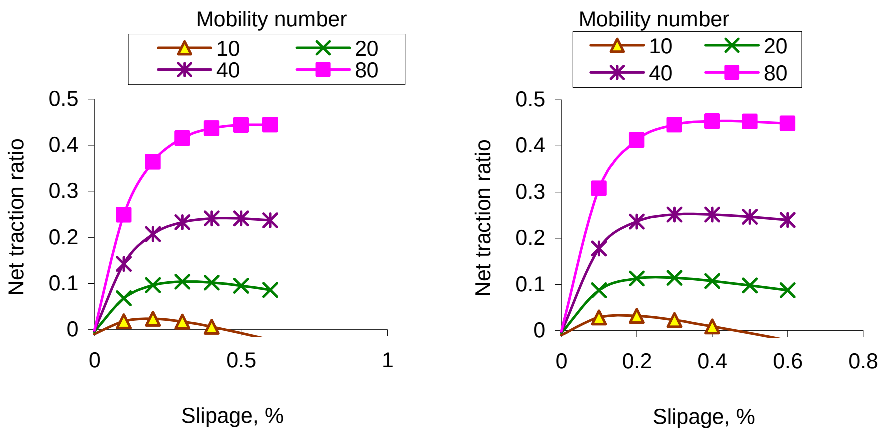


Front wheel **Rear wheel**

Figure 5: The relation between the motion resistance coefficients via the slippage.

C- The net traction ratio

Figure 6 shows that the relation between the net traction ratio (C_{ni}) and the slippage at different tractor mobility number for front and rear wheel. The figure defined that when the slippage increase from 0.1 to 0.6% the net traction ratio increase from 0.118 to 0.129 and 0.092 to 0.127 respectively at front and rear wheel. Then, the relation between the increase of mobility number from 10 to 80, the motion resistance coefficient decrease from 0.008 to 0.360 and from 0.004 to 0.336 respectively at front and rear wheel.



Front wheel **Rear wheel**

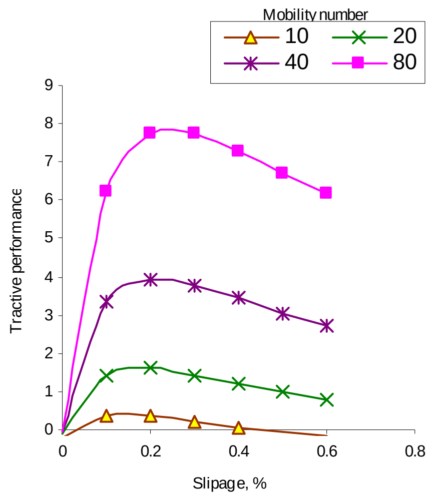
Figure 6: The relation between the net traction ratios via the slippage.

D- The tractive performance of a wheel

Figure 7 demonstrates the relation between the tractive performance of a wheel (F_{hx}) and the slippage at different tractor mobility number. The figure show that when the slippage increases from 0 to 0.6%, the tractive performance of a wheel take a normal distribution curve. The minimum tractive performances of a wheel occur at 0.0 and 0.6 % slippage were ***-0.154 and 1.787, while the maximum at slippage 0.4 % was 2.299. Meanwhile, the relationship between the increases of mobility number from 10 to 80 the tractive performance of a wheel increase from 0.082 to 5.970.

2- Effect of tractor forward speed on drawbar power

To achieve to base a select the suitable machine (tractor and plough) size as indicated to the fuel cost for the tillage operation. For this point, the amount of drawbar power for tillage operation is calculated at different tractor power and forward speed. Figure (8) shows the relationship between the tractor drawbar power and the tractor forward speed at different tractor available power. The figure cleared that the drawbar power has an inversely proportional to the forward speed. At increase the forward speed from 0.97 to 1.81 m/s the drawbar power decreased from 51.18 to 27.43 kW. On the other hand, the increase in tractor available power from 44.13 to 55.16, the drawbar power increases from 33.14 to 41.42 kW. These results are logically and agreement with the results obtained by (Srevastava, 1995) validates this trend.



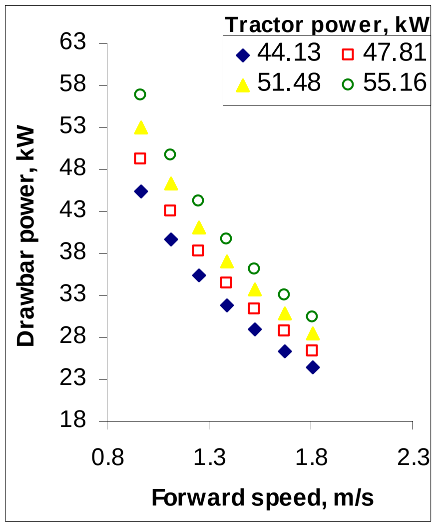


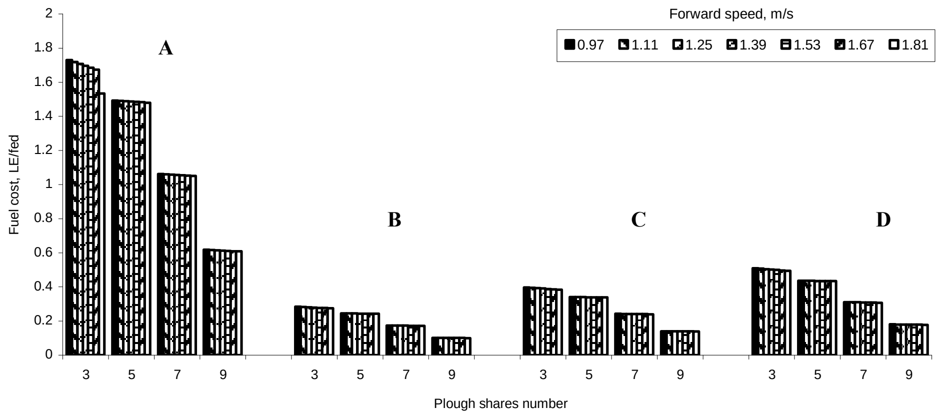
Figure 7: The traction performances of wheels via the slippage.

Figure 8: The tractor forward speed via drawbar power.

3- Cost evolution and plow selection

The tillage operation fuel cost calculates using the previous relations by the Visual Basic program. Therefore, the effect of forward speed on the fuel cost at different chisel plough shares numbers and different tractor available power are illustrated in figure (9). Observed data in figure (9-A) shows that increasing the forward speed from 0.97 to 1.81 m/s decreased the fuel cost from 1.73 to 1.53; 1.493 to 1.480; 1.062 to 1.050 and 0.617 to 0.608 LE/Fed for 3, 5, 7 and 9 chisel plough shares respectively for 44.13 kW tractor power. Also, the same trend was found for 47.81 kW;

51.48 kW and 55.16kW; tractor powers (Figure 9-B; C and D) but the rate of decreases was less than that in the 44.13 kW tractor power



Tractor power (kW): A. 44.13; B. 47.81; C. 51.48; D. 55.16

Figure 9: The relationship between tractor forward speed and fuel cost.

CONCLUSIONS

The research used the economical method to select the tractor and plough for the tillage operation depending on the tractor-plough properties. For this purpose the tractor tire specifications and the chisel plough properties are used by the Visual Basic program to calculate the fuel cost/fed at different tractor power, forward speed and plough width. The results show that the suitable tractor can be used to tillage operation is the 47.81 kW at the all plough width and at different forward speed.

REFERENCES

Al-Suhaibani, S.A.(1989). Costs of using farm machinery for wheat production in Saudi Arabia. Bull. Fac. of Agric., Univ. of Cairo, 40(1): 61-77.

ASAE (1998). Agricultural machinery management data. Agricultural Engineers Year-book. ASAE, st. Joseph, MI 49085.

Burton, P. (2005). How to calculate machinery ownership ad operating costs. Farm Financial Management. South Dakota State Univ. (SDSU), Co. of Ag. and Bio. Sci. http:// agbiopubs. sdstate. edu/ articles/ ec920. pdf.

Butter and Johnnix (1983). Farm mechanization on profit. 1070.

Edward, W. and M. Boehije (1980). Machinery selection considering timeliness losses. Trans. Of the ASAE 23: 810-815.

Gee-Clough, D.; M. McAllister; G. Pearson and D. W. Everndern (1978). The empirical prediction of tractor-implement field performance. *Journal of Terramechanics* 15(2): 81-94

Glancey, J.L.; S.K. Upadhyaya; W.J. Chancellor and J.W. Rumsey (1996). Prediction of agricultural implement draft using an instrumented analog tillage tool. Soil &Tillage Research 37: 47-65.

Harrigan, T.M. and C.A. Rotz (1994). Draft of major tillage seeding equipment. ASAE, Paper No. 94-1533, Michigan, U.S.A.

Hunt, O. (1983). Farm power and machinery management 8th ed. Iowa State Univ. Press, Ames.

Kepner, R.A.; R. Baniner and E.L. Barger (1982). Principles of farm machinery. 2nd. Edition. The AVI publishing company inc., Westport, Connecticut.

Srivastava, A.C. (1995). Engineering Principals of Agric. Machines ASAE Textbook No. 6 Published the ASAE.

Willimam, L. (2005). Farm machinery economic cost estimates for late**.** Extension farm management specialist. Nebraska Univ. Co. of Ag. and Env. sci.

الملخص العربي

التقيم الاقتصادى واختيار المعدات الزراعية

أ.د/ زكريا إبراهيم إسماعيل، أ.د/ ماهر محمد إبراهيم عبد العال، م/ سوسن عبده إمبابى

إن إستخدام الآلات الزراعية المناسبة من حيث القدرة وتكاليف التشغيل يعد من الأهمية فى الإنتاج الإقتصادى للمحصول مع المحافظة على جودة التركيب البنائى للتربة. فى حين أن الإختيار الغير مناسب للآلات يسبب العديد من المشكلات للتربة وتزيد من تكاليف التشغيل وبالتالى تؤثر على المردود الإقتصادى للمحصول. لذا فإن هذه الدراسة تهدف إلى إستخدام النظام الإقتصادى وإختيار الجرار والمحراث المناسبين لعملية الحرث عن طريق معرفة خصائص الجرار والمحراث الهندسية. حيث تم من خلال معرفة مواصفات عجل الجرار وبإستخدام برنامج الـ Visual Basic تم تصميم برنامج لتحديد تكاليف الوقود المستهلك أثناء عملية الحرث عند سرعات تقدم للجرار، وقدرات للجرار، وعرض محراث مختلفة. وقد تم التوصل إلى أن أنسب الجرارات إستخداماً هو الجرار ذو القدرة ٤٧.٨١ كيلووات مع كل المحاريث تحت الدراسة حيث حقق أقل تكاليف للوقود المستهلك للفدان.